BACK TO BASICS

Ziegler-Nichols Methods Facilitate Loop Tuning

Tuning a proportional-integral-derivative (PID) controller is a matter of selecting the right mix of P, I, and D action to achieve a desired closed performance (see "Basics of Proportional-Integral-Derivative Control," *Control Engineering*, March 1998).

The ISA standard form of the PID algorithm is:

$$P = \frac{1.5 \cdot T}{K \cdot d} \qquad T_I = 2.5 \cdot d \qquad T_D = 0.4 \cdot d$$

The variable CO(t) represents the controller output applied to the process at time t, PV(t) is the process variable coming from the process, and e(t) is the error between the setpoint and the process variable. Proportional action is weighted by a factor of P, the integral action is weighted by P/T_I, and the derivative action is weighted by PT_D where P is the *controller gain*, T_I is the *integral time*, and T_D is the *derivative time*.

In 1942, John G. Ziegler and Nathaniel B. Nichols of Taylor Instruments (now part of ABB Instrumentation in Rochester, N.Y.) published two techniques for setting P, T_I, and T_D to achieve a fast, though not excessively oscillatory, closed-loop step response. Their "open loop" technique is illustrated by the *reaction curve* in the figure. This is a strip chart of the process variable after a unit step has been applied to the process while the controller is in manual mode (i.e., without feedback).

A line drawn tangent to the reaction curve at its steepest point shows how fast the process reacted to the step input. The inverse of this line's slope is the *process time constant* T. The reaction curve also shows how long the process waited before reacting to the step (the *deadtime* d) and how much the process variable increased relative to the size of the step (the *process gain* K). Ziegler and Nichols determined that the best settings for the tuning parameters could be computed from T, d, and K as follows:

$$P = 0.75 \cdot P_u \qquad T_I = 0.625 \cdot T_u \qquad T_D = 0.1 \cdot T_u$$

Once these parameter values are loaded into the PID algorithm and the controller is returned to automatic mode, subsequent changes in the setpoint should produce the desired "not-too-oscillatory" closed-loop response. A controller thus tuned should also be able to reject load disturbances quickly with only a few oscillations in the process variable.

Ziegler and Nichols also described a "closed loop" tuning technique that is conducted with the controller in automatic mode (i.e., with feedback), but with the integral and derivative actions shut off. The controller gain is increased until any disturbance causes a sustained oscillation in the process variable. The smallest controller gain that can cause such an oscillation is called the ***ultimate gain*** P_u. The period of those oscillations is called the ultimate period T_u. The appropriate tuning parameters can be computed from these two values according to these rules:

$$CO(t) = P \cdot \left[e(t) + \frac{1}{T_I} \cdot \left(\int e(t)dt \right) - T_D \cdot \left(\frac{d}{dt} PV(t) \right) \right]$$

A reprint of Ziegler and Nichols' 1942 paper can be found in "Reference Guide to PID Tuning" (*Control Engineering*, 1991). Note, however that the tuning rules given in that paper differ from those shown here because Ziegler and Nichols were working with a slightly different form of the PID algorithm. Different PID controllers use different algorithms, and each must be tuned according to the appropriate set of rules. The Rules also change when the derivative or the integral action is disabled.

To order a copy of "Reference Guide to PID Tuning", circle 367 or visit www.controleng.com/info

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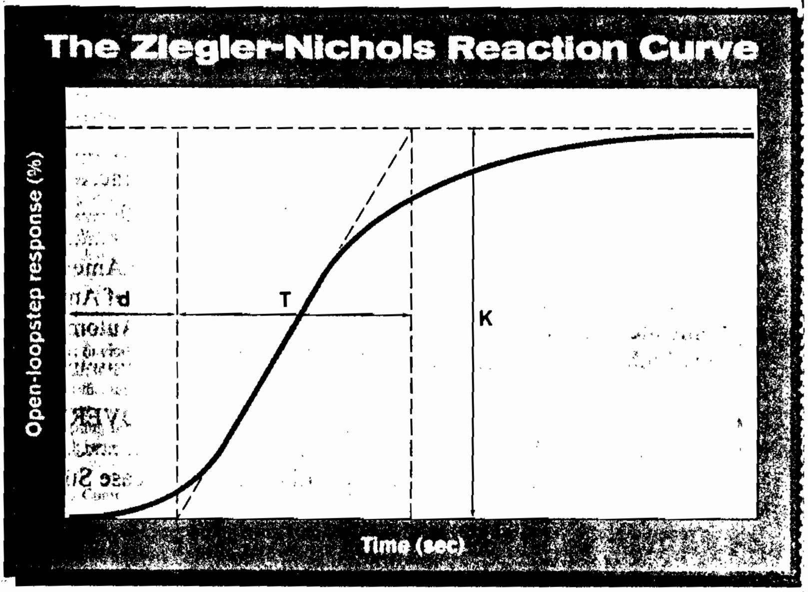

An open loop step test reveals the process's time constant T, deadtime D, and gain K.